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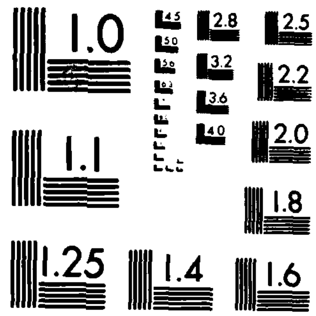

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TECHNICAL REPORT 8303

EVALUATION OF ALKALINE CHEMICAL ADDITION AND ORGANIC LOADING SCHEMES FOR ENHANCEMENT OF SECONDARY TREATMENT AND ANCILLARY NUTRIENT REMOVAL

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Rotating biological contactor (RBC) units were operated as four-stage or single-stage processors at a hydraulic loading rate of 2.0 gpd/sq ft. The removal of total organic carbon (TOC) and ammonia nitrogen was similar in all operational configurations. The biomass was thick and gray in the first stage of the four-stage RBC and corresponded to a dissolved oxygen concentration ranging from 0.6 to 1.2 mg/L. The single-stage RBC had dissolved oxygen concentrations ranging from 1.9 to 3.2 mg/L.

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20. Abstract (continued)

When RBC units were operated on wastewaters containing sodium hydroxide, sodium carbonate, and calcium hydroxide at pH 9.5, the processes receiving sodium salts operated at reduced efficiency as compared to a control. The RBC unit receiving lime-pretreated wastewater removed more TOC than the control unit.

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INTRODUCTION

The Rotating Biological Contactor (RBC) process has been used for upgrading US Army wastewater treatment facilities for secondary treatment and nitrification while the low-level lime addition process has recently received much attention for its phosphorus removal capabilities. This research evaluates the simultaneous use of the two processes; wherein low-level lime addition precedes the RBC, and natural recarbonation depresses the pH.

The RBC was also evaluated for nutrient removal capabilities when operated as a four-stage process compared to a single-stage unit. The studies were designed to assess the applicability of RBC units in upgrading US Army wastewater treatment facilities.

OBJECTIVES

The purpose of this research was to evaluate an RBC wastewater treatment process intended to provide advanced wastewater treatment so that NPDES permit limitations could be met. During initial studies, the wastewater flowed through the four RBC stages in series. Later, the partitions were removed to observe the effects when similar concentrations of nutrients and flow rates were applied to the single-stage RBC configuration.

A secondary objective was to show whether low-level lime addition, for phosphorus removal, improved carbon removal and nitrification, and whether observed effects were due to pH alone, or were dependent upon the various chemicals used for pH adjustment.

LITERATURE REVIEW

RBC technology has been very popular in Europe for several years. Only recently have U.S. engineers recognized this form of biological treatment as a viable alternative exhibiting many advantages over either activated sludge or trickling filter unit processes. In fact, RBC units continue to prove to be effective and economical for removing ammonia and BOD_5. Because the technology is relatively new, the potential exists for even more effective and economical strategies for RBC utilization to mitigate many of the Army's unique waste treatment problems.

In the past, RBC units have been operated in stages for BOD_5 removal and nitrification.[1-3] Because of the plug flow nature of RBC units, the patterns of nutrient removal vary from stage to stage. Steiner[4] has reported that the surface area should be increased in the first RBC stage, thereby reducing surface organic loading rates and increasing available dissolved oxygen levels.

Addition of alkaline chemicals to wastewater treatment systems to increase pH and provide added buffer capacity has been reported for nitrification processes.[5-9] Most recently, Stratta and Long[10] reported that greater heterotrophic growth and more rapid biofilm development were observed to occur at elevated pH levels (pH 8.5).

Schmidt and McKinney[11] and Miller et al.[12] used relatively low doses of lime (150-200 mg/L) to remove phosphorus at pH 9.5. Eighty percent of phosphorus was removed when lime was added to raw wastewater, but no mention was made of changes in the rate of BOD removal during secondary treatment.

Essentially two reasons have existed for adding chemicals to treat wastewater: (1) to aid nitrification, and (2) to precipitate phosphorus. These chemical additions are made during secondary treatment for enhancement of nitrification or to raw wastewater to precipitate phosphorus with low-level lime dosages. No references have been found where alkaline chemicals were added to wastewater to enhance secondary biological treatment.

MATERIALS AND METHODS

PILOT FACILITY

Pilot studies on RBC staging used domestic wastewater from the Fort Detrick housing area. The wastewater was shredded by a grinder pump and pumped at a rate of 7 gallons per minute into a tank, which acted as a grit chamber. The raw, degritted wastewater flowed by gravity to the primary clarifier. The primary effluent flowed by gravity to a wet well where the wastewater passed through the RBC and secondary clarifier.

The detention time for the clarifiers was 2.5 hours. The RBC initially consisted of four compartments in series. The 0.5 meter diameter plastic media disks provided 250 sq ft of surface area for microbial attachment. The disks were rotated through the liquor at 13 rpm, with 40 percent of the fixed-film submerged at any point.

Alkaline chemical addition studies used four parallel test configurations with three RBCs (Fig. 1). The experiment lasted for 70 days. The first stage of each RBC was converted into the first, second, and third stage for a three-stage process. Likewise, the second stage of each RBC, and third and fourth stages. In such a manner, four experimental treatments could be run on four three-stage RBC units simultaneously.

A control at neutral pH was compared to wastewater adjusted to pH 9.5 with slaked lime ($Ca(OH)_2$), sodium hydroxide (NaOH), or sodium carbonate (Na_2CO_3). The wastewater influents were fed in a semi-continuous batch fashion. Feed wastewater was collected daily in the equalization tank and dispensed to mixing and feed tanks, thereby reducing variations in carbon, nitrogen, and phosphorus levels going to the different treatments. Daily composite samples were taken for carbon, nitrogen, and phosphorus analyses.

CHEMICAL ANALYSIS

Total organic carbon (TOC) measurements were made on a Beckman Model 915 TOC analyzer. Ammonia nitrogen concentrations were measured with an Orion specific ion electrode. Dissolved oxygen (DO) determinations were made using

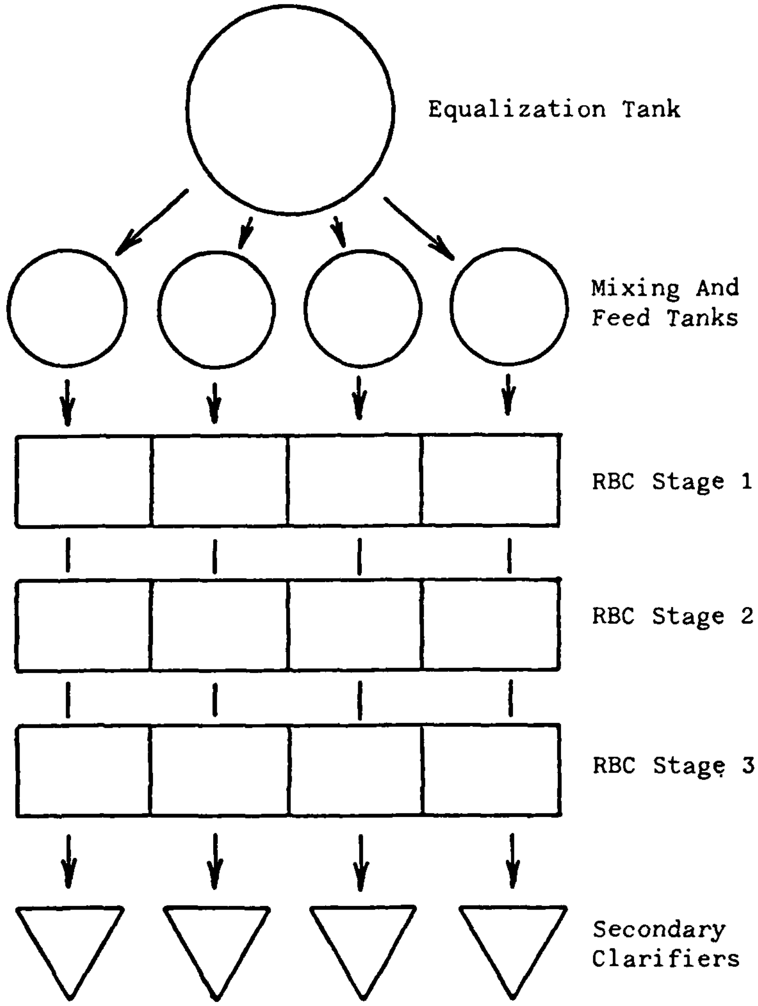

Figure 1. Schematic of wastewater treatment process.

a Delta Scientific Model 2110 DO meter and probe. Nitrate/nitrite nitrogen and phosphorus analyses were made using a Technicon AutoAnalyzer II system according to U.S. Environmental Protection Agency (EPA)-approved Technicon methods. Filtered samples were passed through 0.45 μm membrane filters. All other analyses were performed according to Standard Methods.

RESULTS

This study was divided into two sections. The first section dealt with RBC staging, and the second with alkaline chemical addition.

RBC STAGING

Figure 2 shows a pilot scale RBC operated as a four-stage unit. The biomass was gray on the first stage, where the dissolved oxygen ranged between 0.6 and 1.2 mg/L. In the later RBC stages, the biomass was brown in color, and dissolved oxygen concentrations were found to range between 2.5 and 3.8 mg/L.

Figure 3 shows the influent and effluent TOC concentrations over 70 days of operation. Figure 4 shows the influent and effluent ammonia nitrogen levels over the same period of time. After 40 days of operation, the ammonia nitrogen levels dropped. For reference only, the mean influent concentration is shown as a dotted line, and mean effluent concentrations are shown as a solid line for days 8-38 and 48-70. From Figure 4, there was a 40 day lag before nitrification was observed. This was confirmed by monitoring (NO_2+NO_3)-N concentrations as shown in Figure 5. The drop in NH_3-N coincided with an increase in (NO_2+NO_3)-N levels.

Table 1 shows the mean values of parameters tested across the four stages of the RBC when operated at 2.0 gpd/sq ft. Similarly, Table 2 shows the mean values of parameters tested in a single-stage RBC when operated at 2.0 gpd/sq ft. No differences in effluent quality were demonstrated under these hydraulic loading conditions.

TABLE 1. MEAN VALUES OF TEST PARAMETERS MEASURED AT A HYDRAULIC LOADING RATE OF 2.0 GPD/SQ FT IN A FOUR-STAGE RBC

Parameter	Mean Values (mg/L)					Median Values	
	TOC	ALK	NH_3-N	(NO_2+NO_3)-N	TP-P	pH	^oC
RBC Inf	57	157	15.1	0.03	7.1	6.8	-
Stage 1	40	153	13.5	0.09	6.7	6.9	15.4
Stage 2	32	147	13.2	0.31	6.8	6.9	15.4
Stage 3	28	143	12.5	1.49	6.9	6.9	15.5
Stage 4	24	135	11.3	2.54	6.9	6.9	15.6
RBC Eff	22	124	10.2	3.24	6.9	6.9	-

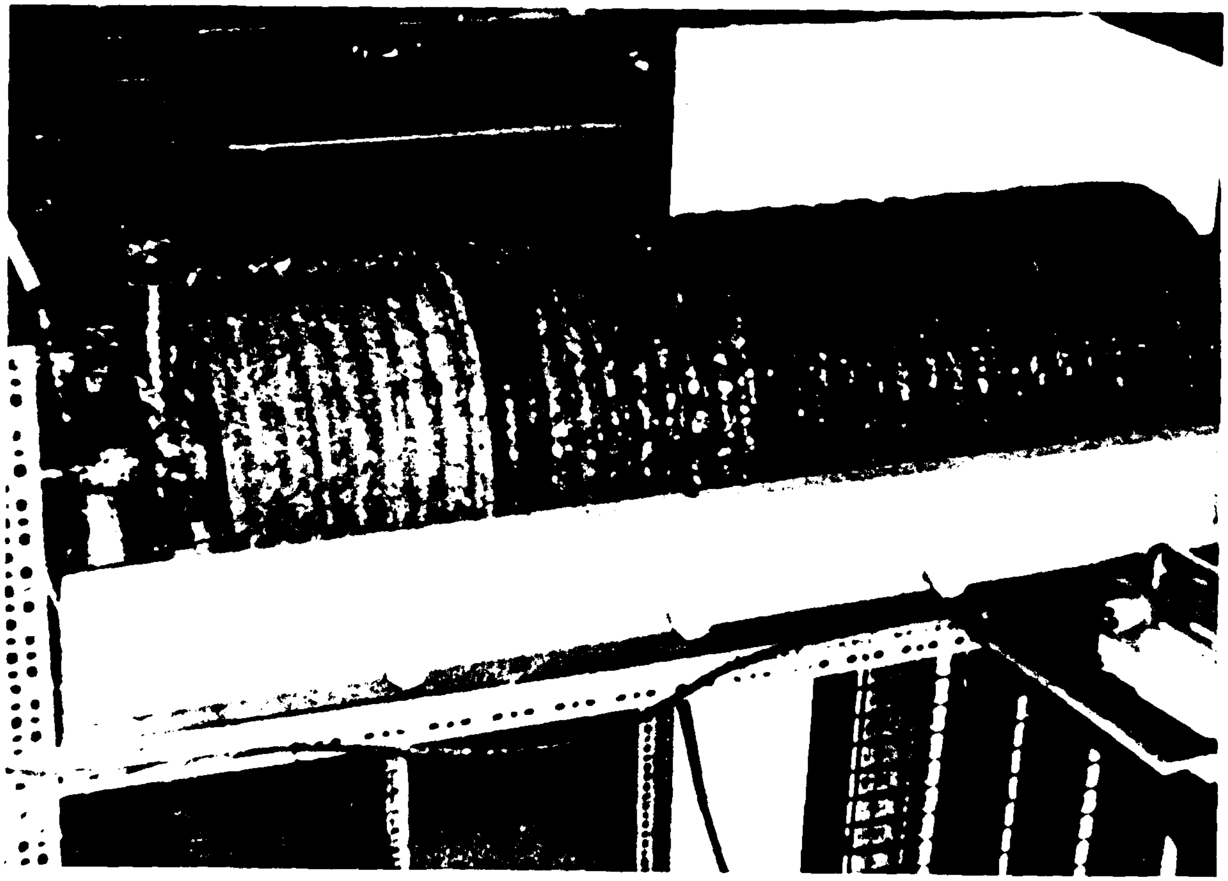

Figure 2. A four-stage RBC with a total surface area of 250 sq ft. The hydraulic loading rate was 2.0 gpd/sq ft.

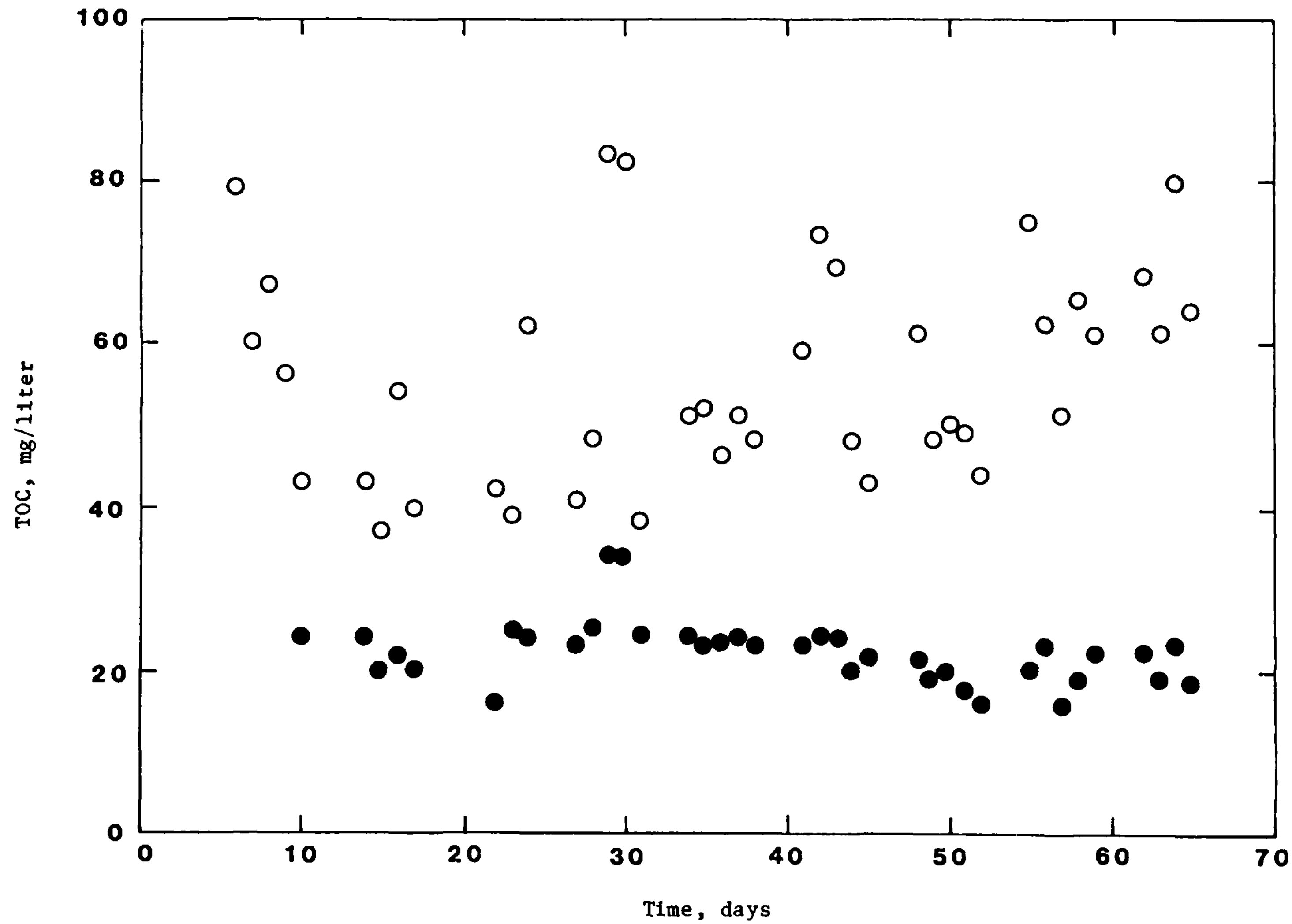

Figure 3. Influent and effluent TOC values are shown with respect to time. Open circles represent influent values, and solid circles correspond to effluent concentrations. The hydraulic loading rate was 2.0 gpd/sq ft.

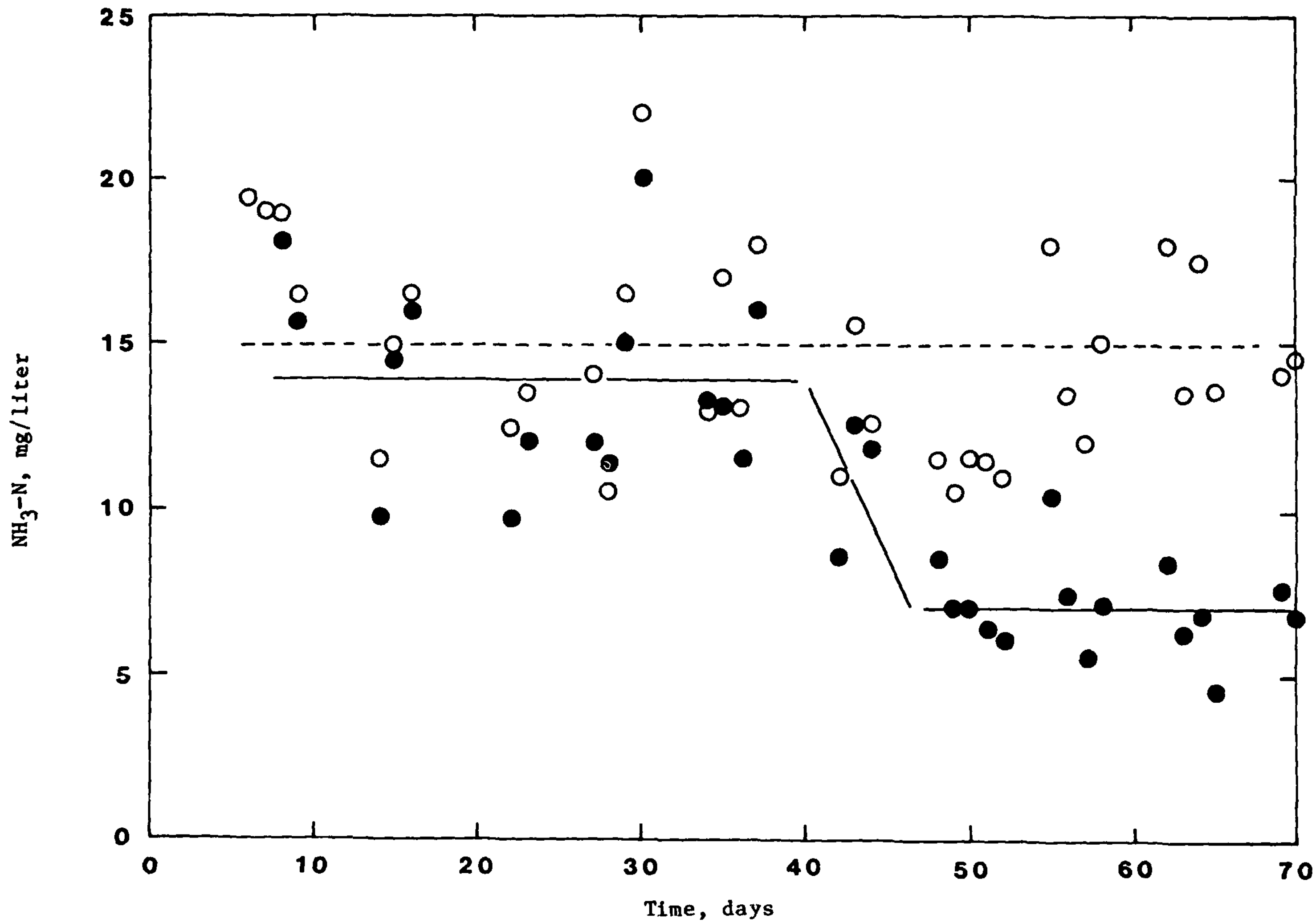

Figure 4. Influent and effluent NH_3-N values are shown with respect to time. Open circles represent influent values, and solid circles correspond to effluent concentrations. The mean influent concentration (15.0 mg/L) is indicated by the dashed line. The mean effluent concentration was initially 13.9 mg/L, but then dropped to 7.2 mg/L once a nitrifying population was established. The hydraulic loading rate was 2.0 gpd/sq ft.

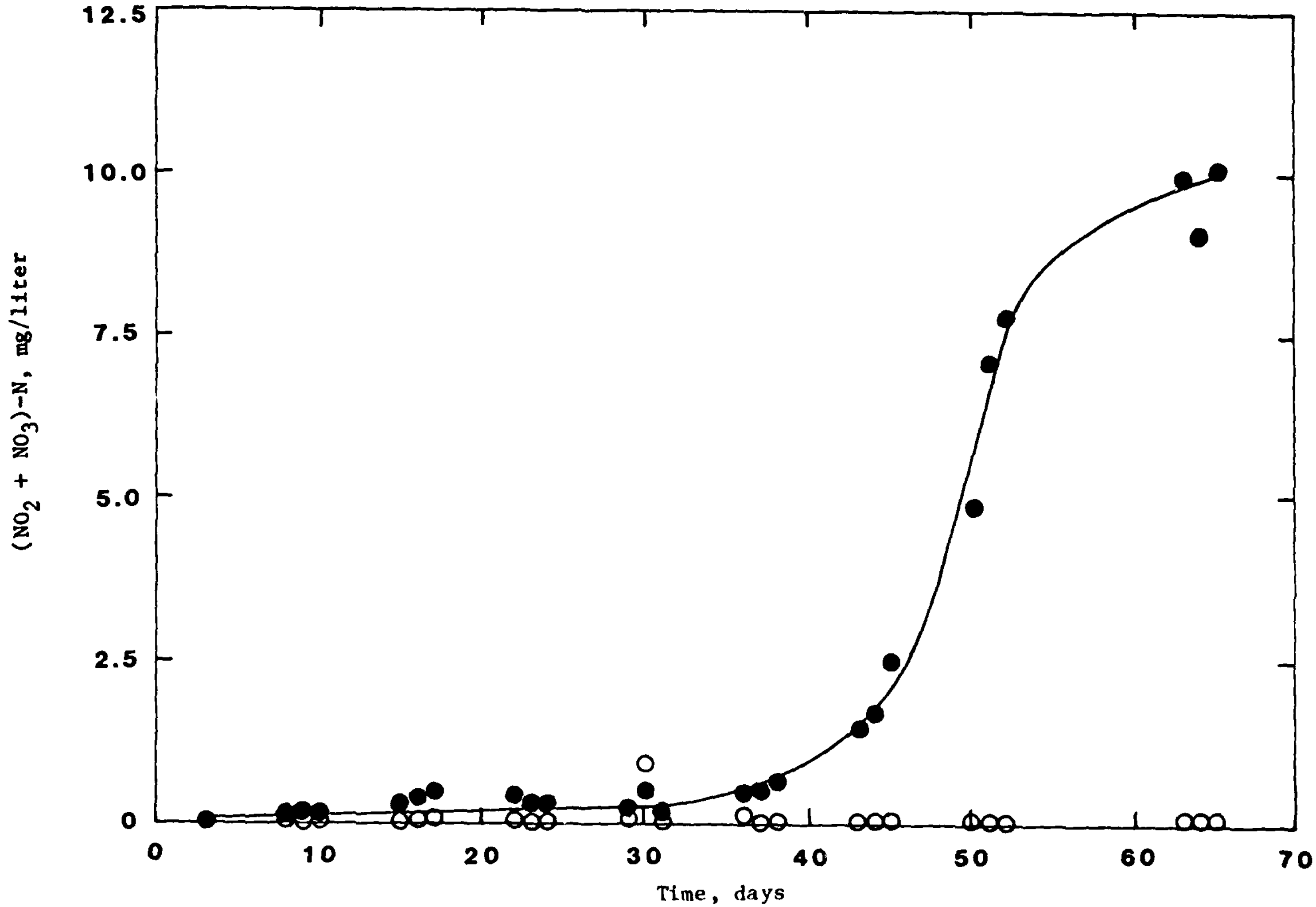

Figure 5. Influent and effluent (NO_2+NO_3)-N values are shown with respect to time. Open circles represent influent values, and solid circles correspond to effluent concentrations. The hydraulic loading rate was 2.0 gpd/sq ft.

TABLE 2. MEAN VALUES OF TEST PARAMETERS MEASURED AT A HYDRAULIC LOADING RATE OF 2.0 GPD/SQ FT IN A ONE-STAGE RBC

Sample Point	Mean Values, mg/L)					Median Values	
	TOC	ALK	NH_3-N	(NO_2+NO_3)-N	TP-P	pH	^oC
Influent	43	196	14.4	0.02	8.7	6.9	17.0
RBC	16	136	8.0	5.47	8.2	6.9	17.0
Effluent	14	131	7.9	5.38	8.1	6.9	17.0

Figure 6 shows the RBC when operated as a single-stage unit. The biomass was brown in color, and the dissolved oxygen ranged between 1.9 and 3.2 mg/L.

ALKALINE CHEMICAL ADDITION

Figure 7 shows the RBC units prior to addition of primary effluent. Figure 8 shows the biomass that had developed over 5 days of operation. The three-stage RBC receiving lime, shown on the left, developed its biofilm more slowly than RBC units receiving sodium hydroxide, sodium carbonate, or no alkaline chemical. On day 11 (Fig. 9), the control and lime-treated biofilms covered the available surface, but the sodium hydroxide and sodium carbonate-treated biofilms began sloughing. After the initial sloughing, biofilms maintained a consistent appearance for the remainder of the study period (Fig. 10). Figures 11 through 14 show the primary effluent and secondary effluent TOC concentrations applied to and leaving each RBC. These scatter diagrams serve to demonstrate the instability of the RBC units receiving sodium hydroxide and sodium carbonate for pH adjustment. Table 3 shows the mean concentrations of TOC, NH_3-N, and total phosphorus (TP) for each test condition. It can be seen that TOC, NH_3-N, and TP concentrations were reduced by the lime treatment process to a greater extent than was evident in the control, sodium hydroxide, or sodium carbonate processes.

Table 4 lists the median pH values for each process tested. Biological recarbonation of high pH effluent was similar for lime and sodium carbonate treated wastewater. The wastewater treated with sodium hydroxide may have provided too harsh an environment for many of the microorganisms in the biofilm. Table 5 substantiates this hypothesis by demonstrating that little removal of TOC occurred in the NaOH treated wastewater feed tank, whether due to settling or biological utilization.

In Table 5, TOC removal, expressed as removal by clarification, was the amount of TOC removed by flocculation/sedimentation and biological oxidation which occurred before the wastewater was fed into the RBC units. TOC removal in the RBC stages was expressed as the amount of TOC removed relative to the amount of TOC entering each stage. Cumulative biological removal accounts for the loss of TOC across the RBC units only. The overall removal column accounts for the change in TOC from the degritted raw sewage to the secondary effluent.

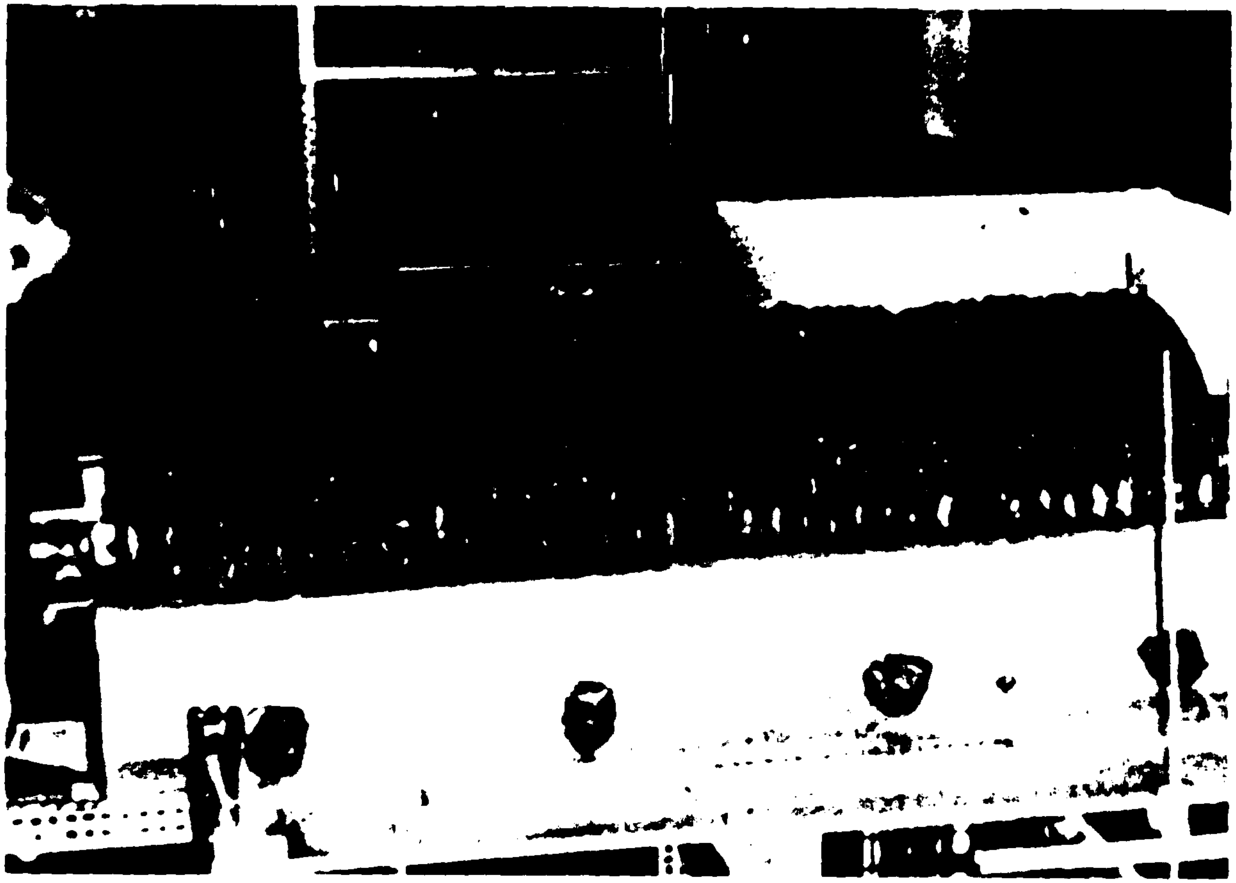

Figure 6. A single-stage RBC with a total surface area of 250 sq ft. The hydraulic loading rate was 2.0 gpd/sq ft. The wastewater temperature was $17.0^{\circ}C$.

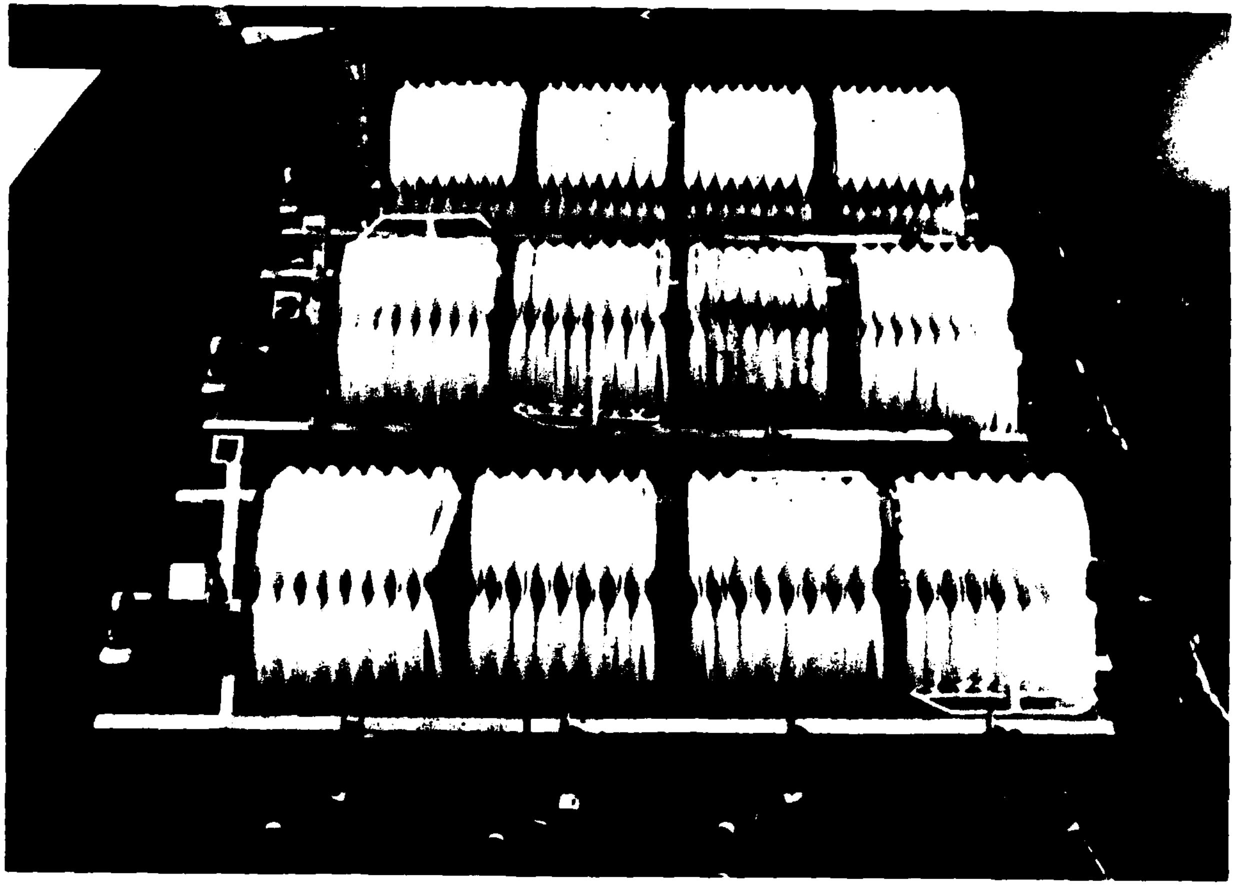

Figure 7. RBC treatment units before wastewater was applied. Flow was directed from top to bottom with the RBC in the foreground being the third stage for each wastewater to be processed.

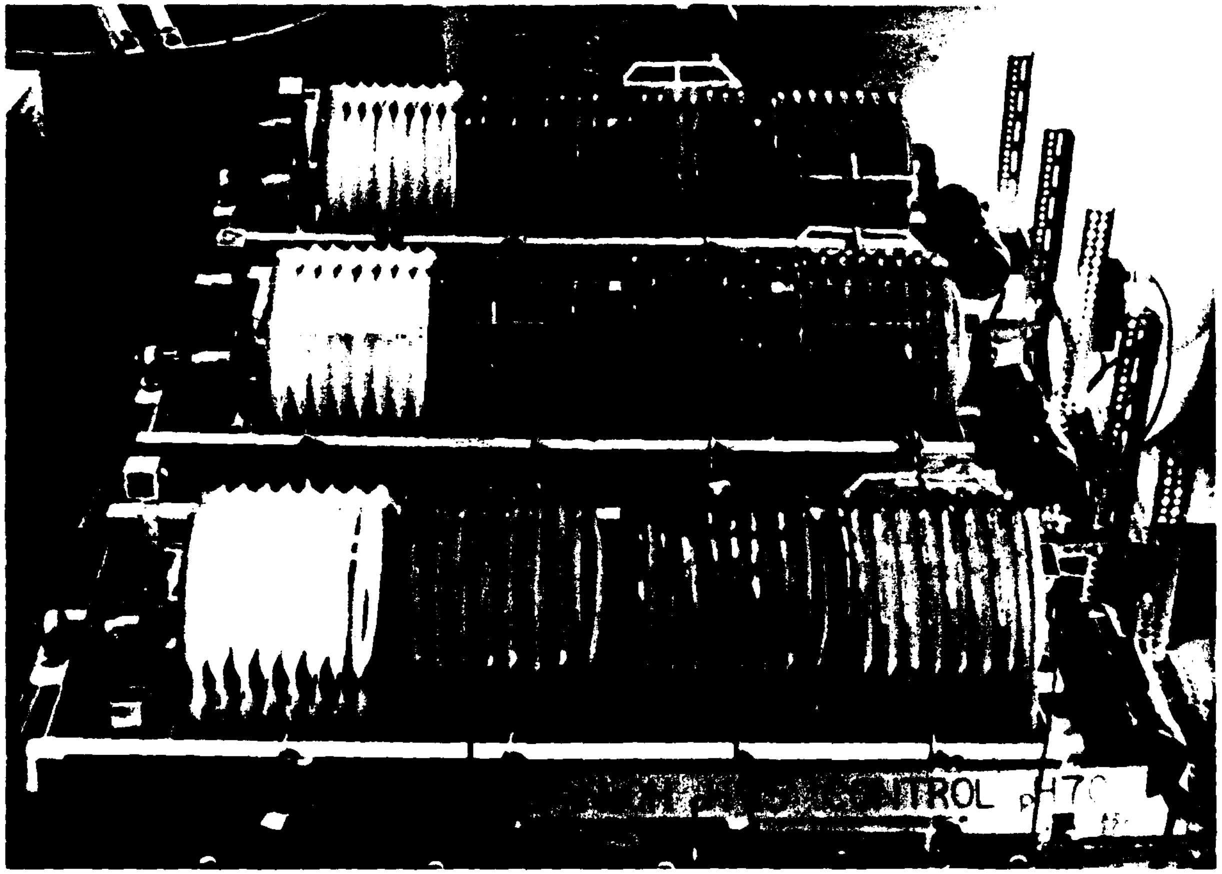

Figure 8. RBC treatment units on the 5th day of operation. Chemical additives from left to right are calcium hydroxide, sodium carbonate, sodium hydroxide, and none (control).

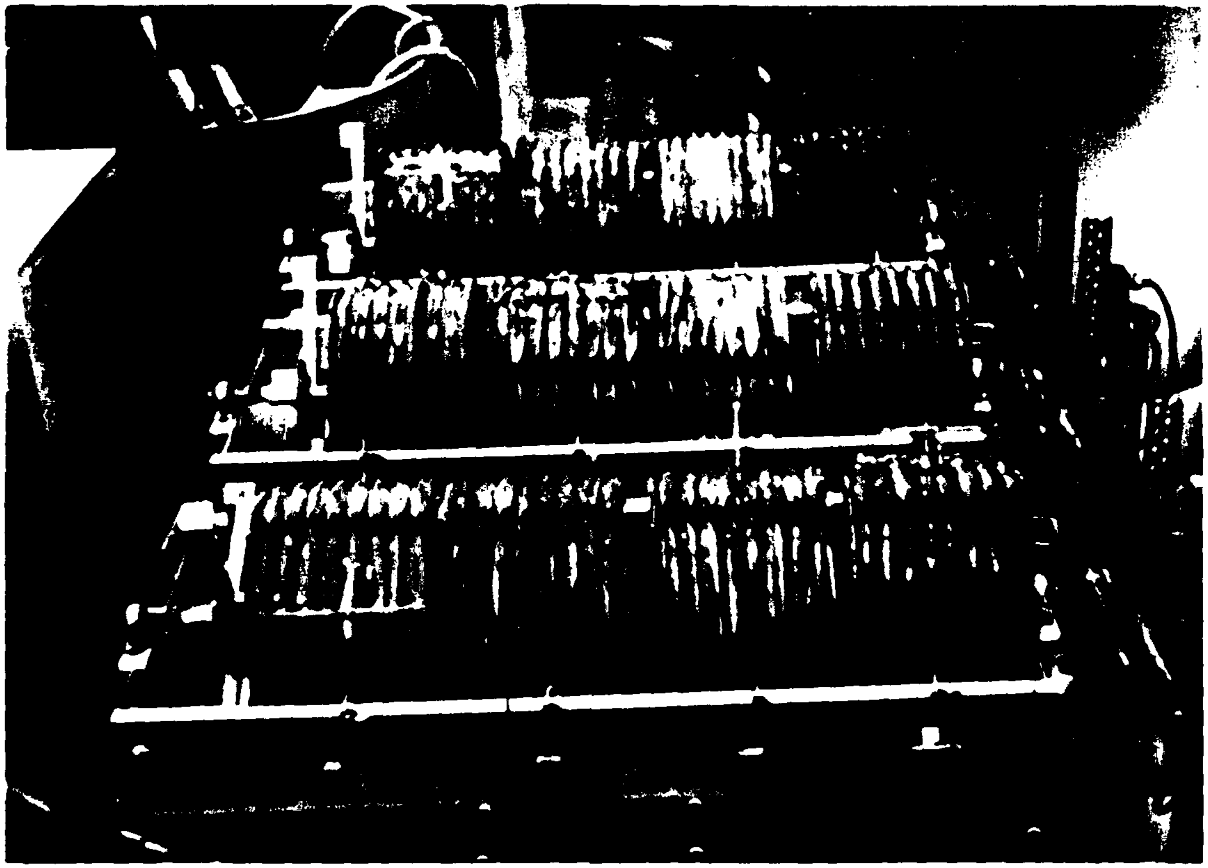

Figure 9. RBC treatment units on the 11th day of operation. Sodium carbonate and sodium hydroxide treated wastewaters have already demonstrated sloughing biomass.

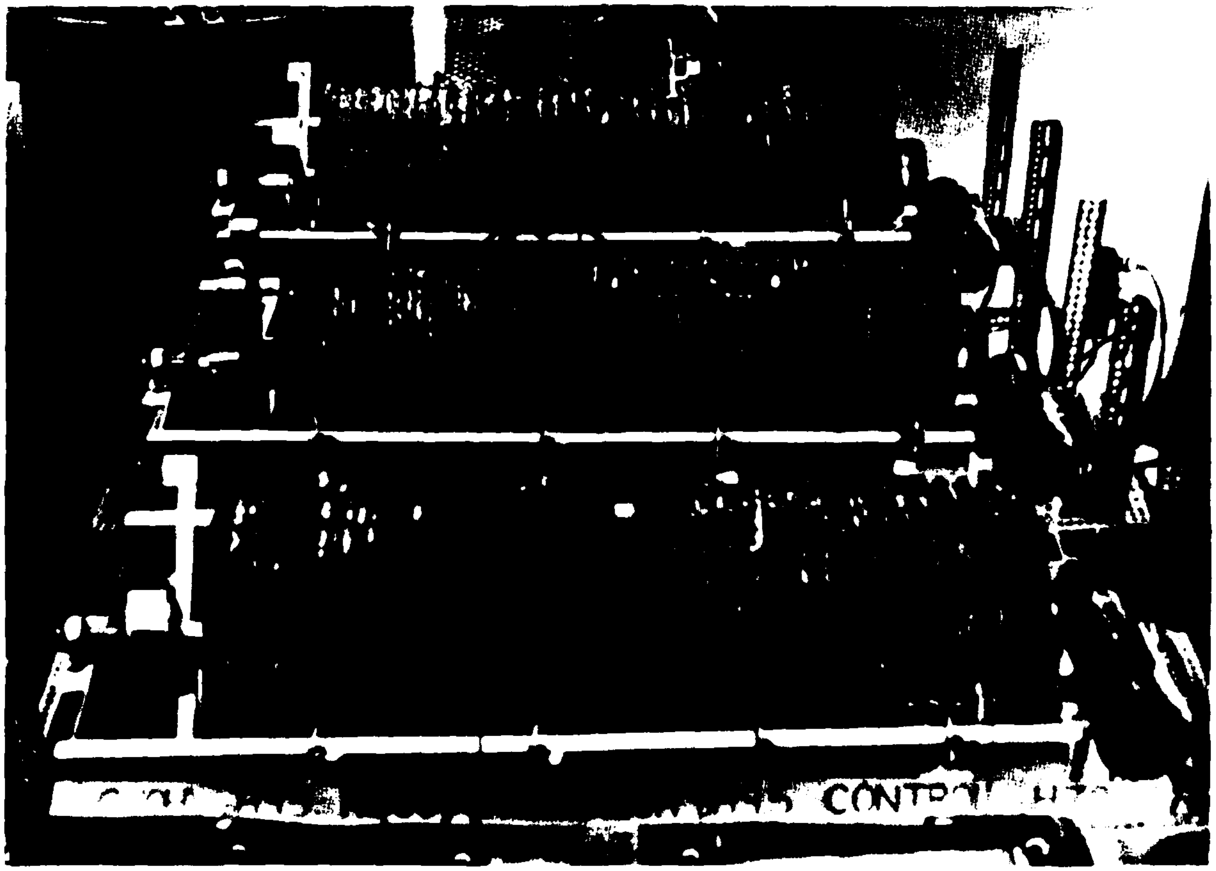

Figure 10. RBC treatment units on the 43rd day of operation.

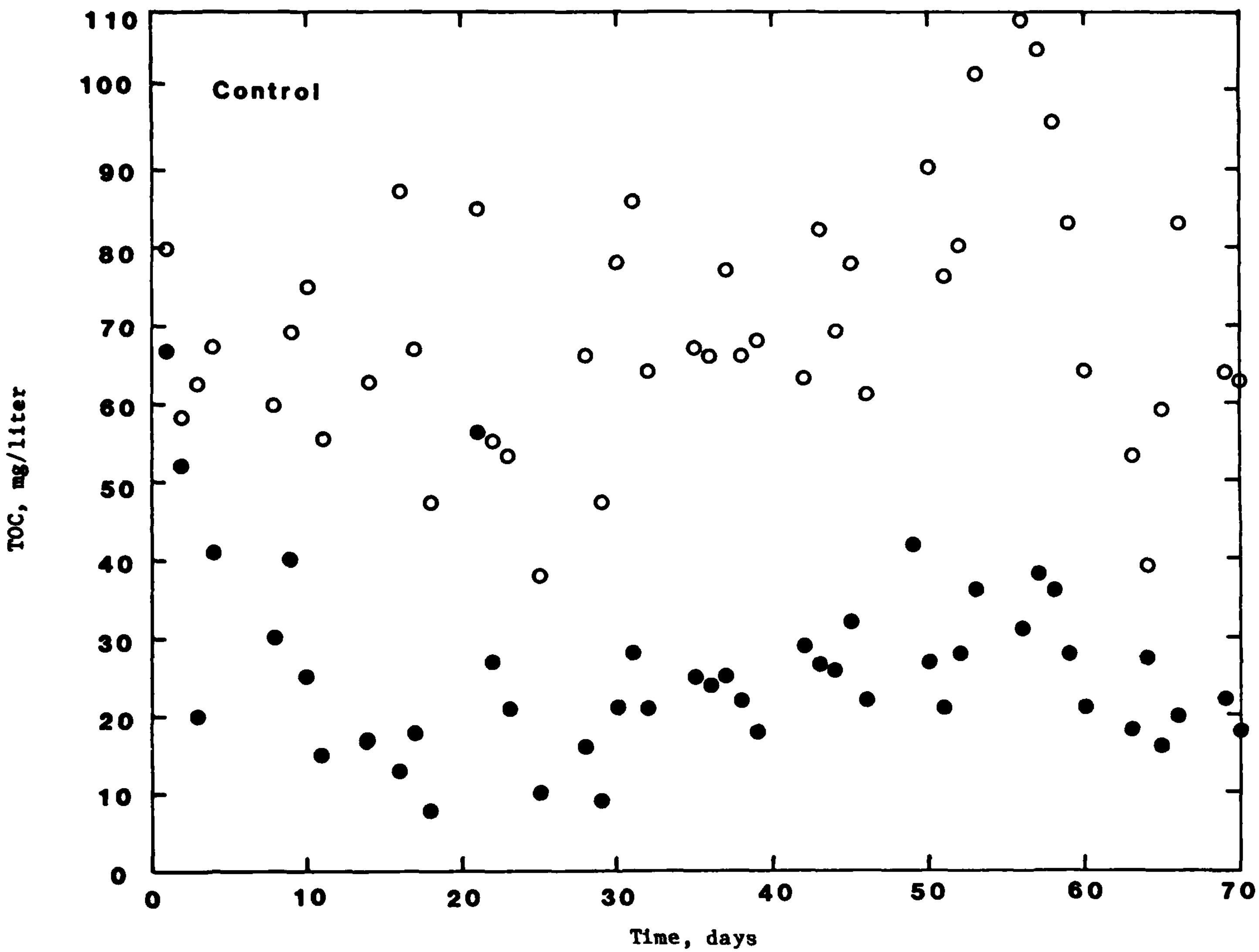

Figure 11. Diagram of influent and effluent TOC data points for the control RBC over a 70-day study. Influent and effluent values are represented by open and closed circles, respectively.

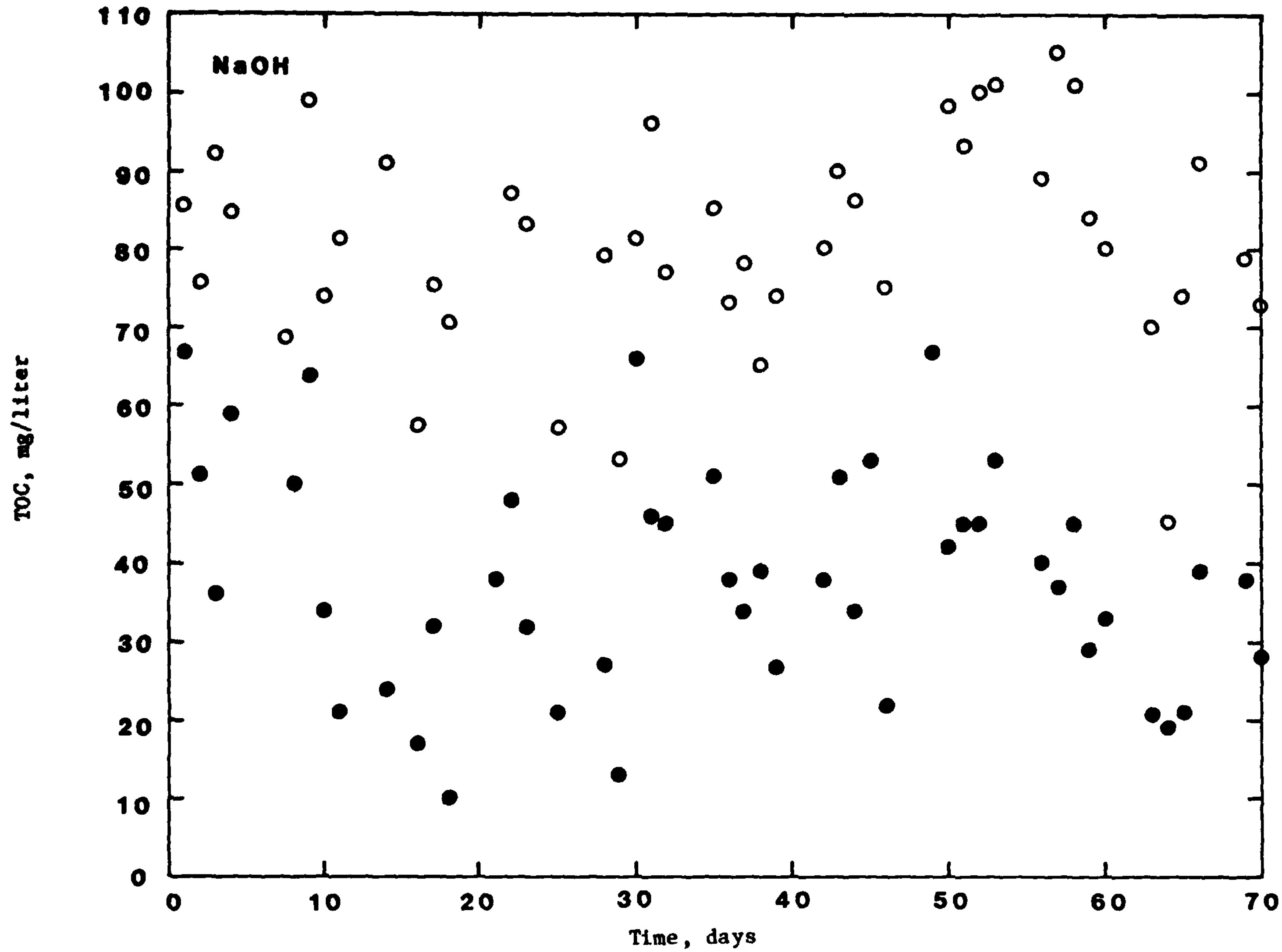

Figure 12. Diagram of influent and effluent TOC data points for sodium hydroxide-treated wastewater applied to an RBC over 70 days operation. Influent and effluent values are represented by open and closed circles, respectively.

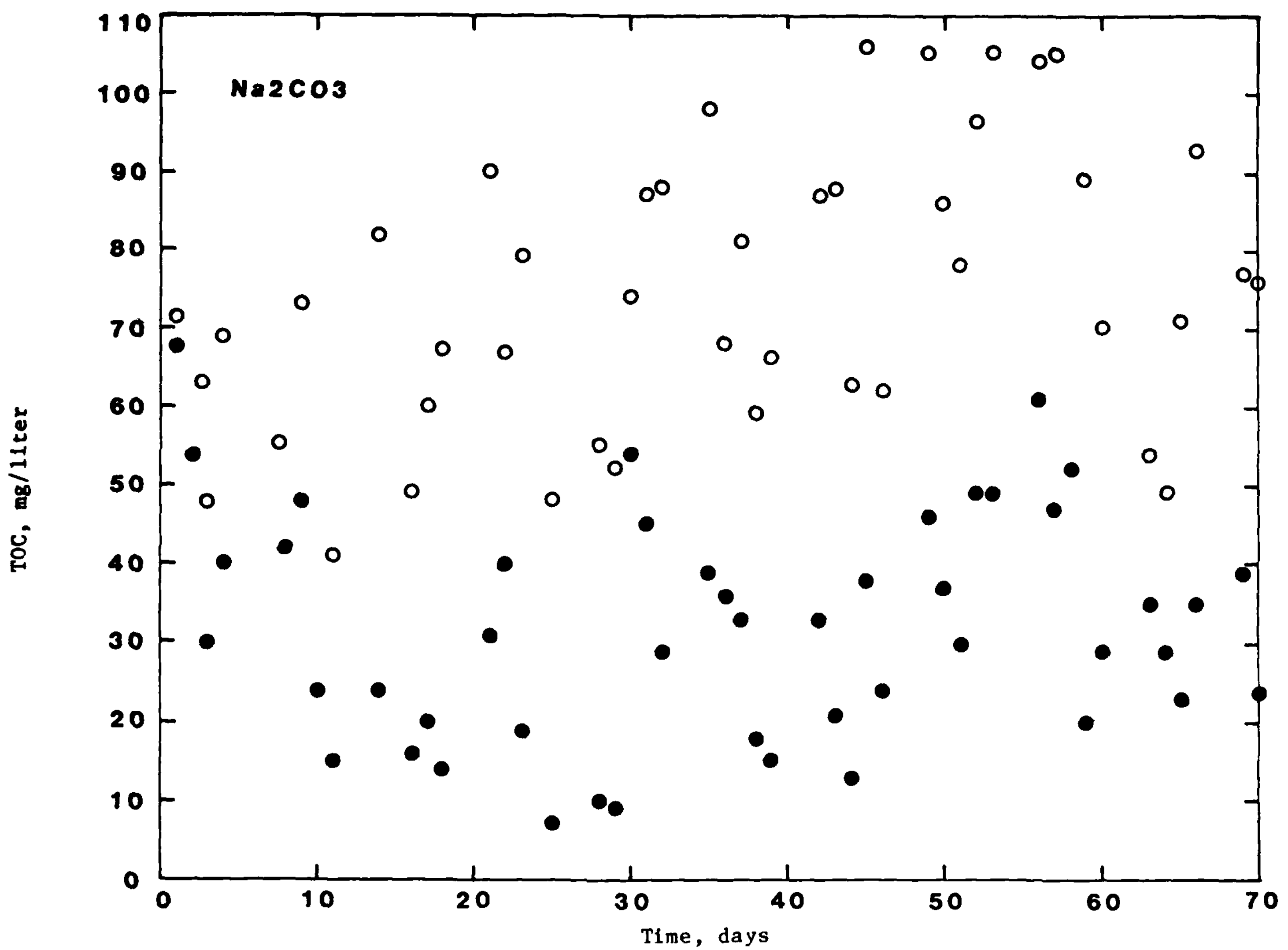

Figure 13. Diagram of influent and effluent TOC data points for sodium carbonate-treated wastewater applied to an RBC over 70 days operation. *Influent and effluent* values are represented by open and closed circles, respectively.

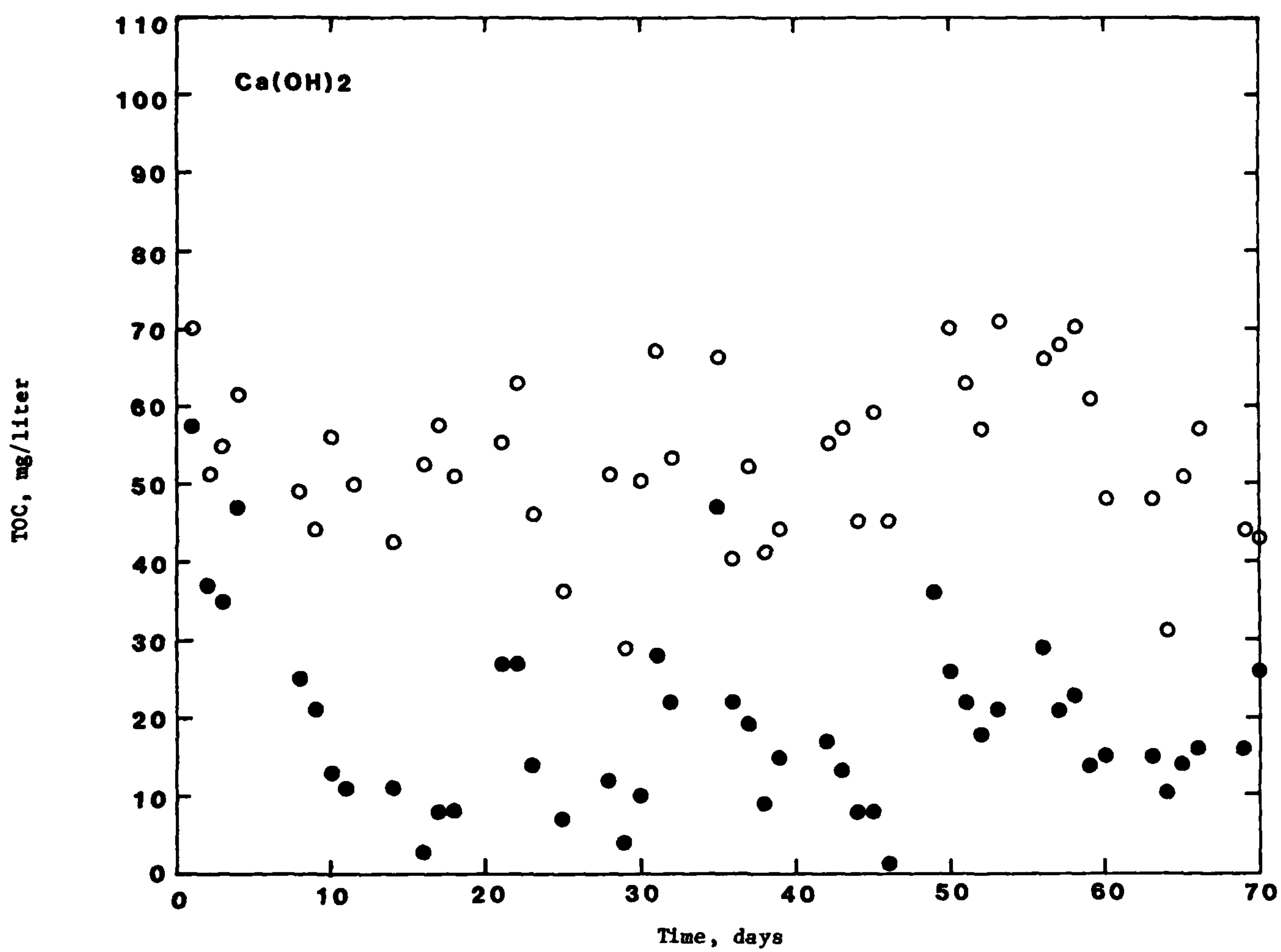

Figure 14. Diagram of influent and effluent TOC data points for calcium hydroxide-treated wastewater applied to an RBC over 70 days operation. Influent and effluent values are represented by open and closed circles, respectively.

TABLE 3. NUTRIENT CONCENTRATIONS AS A FUNCTION OF ALKALINE CHEMICAL APPLIED

	Control	NaOH	Na_2CO_3	$Ca(OH)_2$
	TOC mg/L			
Degritted Raw Sewage	88	88	88	88
Primary Effluent	72	81	79	50
RBC Stage #1	53	66	60	34
#2	35	50	42	20
#3	25	40	32	17
Secondary Effluent	23	35	27	16
	NH_3-N mg/L			
Degritted Raw Sewage	25.6	25.6	25.6	25.6
Primary Effluent	26.3	23.7	23.0	22.0
RBC Stage #1	25.8	22.9	22.6	21.8
#2	24.8	22.6	22.1	21.4
#3	25.2	22.6	22.0	19.5
Secondary Effluent	25.0	22.6	21.9	20.0
	TP-P mg/L			
Degritted Raw Sewage	12.2	12.1	12.2	12.2
Primary Effluent	10.7	9.5	9.2	3.1
RBC Stage #1	10.0	9.0	8.8	3.0
#2	9.6	8.5	8.3	2.8
#3	9.5	8.0	8.1	2.7
Secondary Effluent	9.3	7.8	7.8	2.6

TABLE 4. MEDIAN pH VALUES OF WASTEWATER TREATED WITH VARIOUS CHEMICALS

Sample Point	Control	NaOH	Na_2CO_3	$Ca(OH_2)$
Degritted Raw Sewage	7.2	7.2	7.2	7.2
Primary Effluent	7.2	9.5	9.5	9.5
RBC Stage #1	7.2	9.1	9.5	9.1
#2	7.3	8.9	8.6	8.7
#3	7.2	8.6	8.3	8.2
Secondary Effluent	7.2	8.5	8.2	8.1

TABLE 5. REMOVAL OF TOC FROM HIGH pH WASTEWATERS

Chemical Applied	TOC, % Removed Clarification	Stage 1	Stage 2	Stage 3	Cumulative Biological Removal	Overall Removal
Control	19	25	32	28	63	70
NaOH	7	22	20	25	54	57
Na_2CO_3	10	26	29	24	61	65
$Ca(OH)_2$	40	32	36	22	66	80

Lime treated wastewater applied to an RBC produced the highest removal of TOC. Forty percent of the TOC initially present in the degritted raw sewage was removed by flocculation/sedimentation and biological removal that occurred in the RBC feed tank. The first stage of the RBC removed 32 percent of the TOC which remained. Likewise, the second RBC stage removed 36 percent of the TOC which passed through stage 1. After the lime treated effluent had passed through all three RBC stages, a total of 66 percent of the TOC entering the RBC had been biologically removed. The overall TOC removal, considering both sedimentation and biological oxidation, was 80 percent for lime pretreatment compared to 70 percent for the control unit.

Figure 15 shows that lime pretreatment also lowered the suspended solids concentration as compared to the control treatment. Wastewater treated with sodium hydroxide or sodium carbonate had elevated suspended solids levels with respect to the control treatment.

CONCLUSIONS

1. Little difference in effluent quality was observed when an RBC was operated as a four-stage unit compared to operation as a single-stage process.

2. When the RBC was operated as a four-stage process, the dissolved oxygen was depressed in the first stage, where thick gray biomass was observed.

3. The single stage RBC had a biofilm with uniform color and consistency; the dissolved oxygen level never fell below 1.9 mg/L.

4. RBC units receiving sodium hydroxide or sodium carbonate for pH adjustment had decreased TOC removal rates compared to a control RBC unit.

5. Lime addition not only reduced phosphorus concentrations in secondary effluents, but also allowed for greater overall removal of TOC as compared to a control RBC unit.

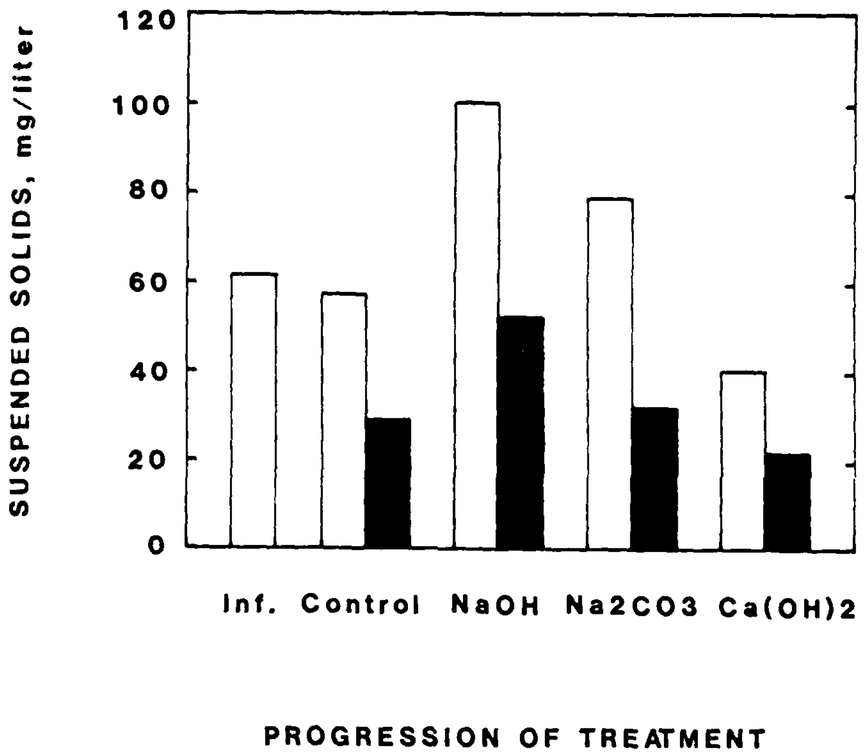

Figure 15. Suspended solids concentrations in wastewater treated with various alkaline chemicals. Blank elements indicate influent values, and solid elements represent effluent levels as above.

RECOMMENDATION

In situations where problems exist in phosphorus and ammonia nitrogen removal, low-level lime addition should be considered for wastewater pretreatment. The benefits of lime pretreatment* of raw wastewater include phosphorus removal and increased removal of organic carbon before secondary treatment. Also, lime has been used to increase nitrification rates when added to trickling filter effluents.[10]

* It should also be noted that a further reduction of suspended solids can be achieved by lime coagulation and sedimentation when ferric chloride is used as a coagulant aid at approximately 5 mg/L.

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LIST OF ABBREVIATIONS

Inf	Influent
Eff	Effluent
TOC	Total organic carbon
Alk	Alkalinity
NH_3-N	Ammonia-nitrogen
(NO_2+NO_3)-N	Nitrite + nitrate-nitrogen
SS	Suspended solids
TP	Total phosphorus
RBC	Rotating biological contactor

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